THE CHEMICAL EVOLUTION OF STARBURST NUCLEUS GALAXIES

R. Coziol[1,4], T. Contini[2], E. Davoust[2]

and

S. Considère[3]

ABSTRACT

The metallicities derived from spectroscopic observations of a sample of Starburst Nucleus Galaxies (SBNGs) are compared to those of several other types of galaxies (normal giant galaxies, Irregular and HII galaxies) drawn from the literature. The SBNGs are deficient in metals with respect to normal galaxies of same morphological type, suggesting that *SBNGs are galaxies still in the process of formation.*

Breaking the SBNGs into early–types (Sb and earlier) and late–types reveals that the former seem to follow the same linear luminosity–metallicity relation as the irregular and elliptical galaxies, whereas the latter and the giant spirals show comparable (0.2 and 0.3 dex) excess abundances with respect to the linear relation. This difference between the two types of SBNGs is consistent with the predictions of the model of hierarchical formation of galaxies: the early-type SBNGs are building their bulges by successive mergers of small stellar and gaseous systems, while the late–type SBNGs are mostly accreting gas to form a disk.

[1]Laboratório Nacional de Astrofísica - LNA/CNPq, Rua Estados Unidos, 154, Bairros das Nacões - Itajubá/MG (Brasil), CEP 37500-000

[2]UMR 5572, Observatoire Midi–Pyrénées, 14 avenue E. Belin, F-31400 Toulouse, France

[3]EP CNRS 123, Observatoire de Besançon, B. P. 1615, F-25010 Besançon cedex France

[4]On Leave of absence from the Institúto Nacional de Pesquisas Espacias/INPE

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1. Introduction

The elemental abundance in galaxies is an essential parameter for understanding how galaxies evolve, and provides important constraints on current models for their formation. It also constrains models for stellar evolution and for primordial nucleosynthesis.

The elemental abundance in spiral galaxies was first thought to depend essentially on local properties of the interstellar medium, such as the density of gas. Recent studies have shown that it depends predominantly on global properties of the galaxies, such as mass or Hubble type, but the situation is still rather confused. Garnett & Shields (1987) find evidence for a correlation between mean metal abundance and total luminosity. Oey & Kennicutt (1993) find no such correlation for early-type (Sa to Sb) galaxies, but note that early-type galaxies have higher metal abundances than late-type ones. Using a different sample of galaxies, Zaritsky, Kennicutt & Huchra (1994; hereafter ZKH) confirm that the abundance is correlated with total luminosity; they also state that stochastic events, such as starbursts and external accretion of matter, could only contribute to the scatter in the abundance values.

A first evidence that starbursts are in fact a driving mechanism in the chemical evolution of spiral galaxies has been presented by Coziol (1996b). He finds that the Starburst Nucleus Galaxies (hereafter SBNGs) are less chemically evolved than galaxies with similar morphologies and comparable luminosities, and that the SBNGs seem to follow the same luminosity–metallicity linear relation as the irregular and elliptical galaxies.

In this *Letter*, we use new spectroscopic data on a large sample of Markarian SBNGs (Contini 1996) to establish Coziol's claim on firmer observational ground. In other words, we compare the global chemical characteristics of early- and late-type SBNGs with those of normal giant galaxies, of HII galaxies, of irregular and elliptical galaxies.

2. The different samples

Our sample of SBNGs is composed of 62 Markarian barred galaxies from the study of Contini (1996), of a sample of 40 compact Kiso galaxies (Comte et al. 1994) and of a sample of 20 SBNGs from the MBG survey (Coziol et al. 1994, 1996). The starburst nature of all these galaxies was established by the different authors in the original articles using standard diagnostic diagrams of emission line ratios (Baldwin et al. 1981, hereafter BPT; Veilleux & Osterbrock 1987, hereafter VO).

The comparison samples were taken from the literature. We used the sample of normal spiral galaxies of ZKH, to which we added the sample of early–type spirals observed by Oey & Kennicutt (1993). The sample of irregular galaxies is from Skillman et al. (1989). As samples of HII galaxies (see Coziol 1996a, for a definition of the two main types of starburst galaxies), we used those of the Calán-Tololo survey (Peña et al. 1991) and those of the catalogue of Terlevich et al. (1991). Finally, we also included a sample of luminous Arp interacting galaxies (Keel et al. 1985).

Since we are using various sources for our samples of galaxies, we must verify the consistency of the derived abundances. Those of the giant spiral galaxies are average values; they were estimated by measuring the mean values, normalized to a mean radius, of the abundances of at least 10 disk HII regions. For the starburst galaxies, the measures were

done with long slits centered on the nucleus (SBNGs) or on the most luminous part of the galaxy (HII galaxies). Because the HII galaxies have small angular dimensions, the slit aperture usually covers the entire galaxy and the measured metallicities are therefore good estimates of their mean metallicities. In the case of the SBNGs, which have higher angular dimensions than the HII galaxies, the abundances are mostly those of the nuclei. In normal spirals, the metallicities usually increase toward the center of the galaxies (ZKH); preliminary results indicate that this is probably also true for the SBNGs (Considère et al. in preparation). The abundances of the SBNGs represent therefore upper limits of their mean metallicities.

The metallicities ([O/H]) of the HII galaxies were estimated by determining the electron temperature using [OIII]λ4363. For the SBNGs this line is usually not observed and we used the metallicity index R_{23} (Pagel et al. 1979), or some comparable methods based on R_{23}. We verified that all these methods give similar results. One of the methods (Coziol et al. 1994) is based on the calibration of a diagnostic diagram using HII region samples where the electron temperature is determined using [OIII]λ4363 and covering metallicities between -0.9 and 0.3 dex. The differences between the metallicities obtained by this method and the others are generally much lower than the typical uncertainty of 0.2 dex associated to each of these methods.

The redshifts and the adopted morphologies for all the galaxies are as given in the original papers or were found in NED[5] or in LEDA[6]. For some galaxies, the B magnitudes were not given in the original papers and were found in NED. No internal extinction correction was applied. All the absolute magnitudes were determined or corrected for the value $H_o = 75$ km s^{-1} Mpc^{-1}.

3. Results

Table 1 gives the mean absolute magnitudes and metallicities for the different samples of galaxies. The early–type SBNGs are poorer in metals on average by 0.2 dex with respect to the late–type SBNGs and by nearly 0.3 dex with respect to the giant spirals. On the other hand, both types of SBNGs share the same distribution in luminosities. This is a strong indication that the differences between the two types of SBNGs are real, and not a selection effect. Moreover, the low abundance cannot be an artefact caused by the small aperture used in our spectroscopic setup, since this tends to raise, rather than lower, the measured abundance.

In figure 1, we compare the behavior of the abundance with respect to morphology for the SBNGs and the normal and HII galaxies. As expected, the normal galaxies show a morphology–metallicity trend: the metallicity increases from the late–type spirals to the early–type ones. This trend is not observed for the HII galaxies, which have lower mean abundances than normal galaxies; this is not new and is related to the low luminosities and small masses of these galaxies. But our luminous SBNGs do not follow the morphology–metallicity trend either. Although chemically richer than the HII galaxies, the SBNGs are nonetheless significantly deficient in metals as compared to normal galaxies. In figure 1, this phenomenon is most evident for the early-type SBNGs ($T \leq 3$).

Our results are based on the assumption

[5]The NASA/IPAC Extragalactic Database

[6]Lyon Meudon Extragalactic database

that the main source of ionization of the gas in the SBNGs is OB stars, like in normal HII regions. This is implicit in the definition of starbursts based on diagnostic diagrams of emission line ratios. But the spectra of the SBNGs show one important difference with respect to those of disk HII regions: their ratios [NII]/Hα are on average 0.2 dex higher (Coziol et al. 1996). If this excess emission corresponds to a supplementary nonthermal ionizing source, like a hidden AGN or shock–heated gas, such as embedded supernova remnants, this could indeed produce a false effect of lower metallicity.

To verify this hypothesis, we compare in figure 2 the ratios [SII]/Hα with the ratios [NII]/Hα. Both ratios would increase in the presence of a nonthermal ionizing source. We find no relation between the ratios of these two lines. We also verified that there is no relation between [SII]/Hα or [NII]/Hα and the metallicity. In figure 2, the dot–dashed line corresponds to the lower limit predicted by shock models (see VO and Ho et al. 1993). The values for the SBNGs are well below this value. In fact, the majority of SBNGs have [SII]/Hα ratios within 0.2 dex of the mean ratios observed in normal HII regions (Greenawalt & Walterbos 1996). In figure 2, we also see that very few SBNGs have Nitrogen emission above the lower limit proposed by Ho et al. (1993) for transition galaxies (that is galaxies with AGN + HII region spectra). Véron et al. (1996) also found very few transition galaxies. The presence of a hidden AGN in the SBNGs is also ruled out because of the weakness of [OI]λ6300: only $\sim$ 40% of our galaxies show this line and their ratios Log([OI]/Hα) ≤ -1.3 are similar to those of normal HII regions (BPT, VO). We conclude that there is nothing in the spectra of the SBNGs to prevent us from applying normal HII region models to SBNGs, and the low metallicity of the SBNGs is therefore real.

A first assumption that comes to mind for explaining the low metal abundance in SBNGs is massive accretion of unprocessed gas during gravitational interaction with another galaxy (Coziol 1996b), which would explain both the reduced elemental abundance and the starburst. But most SBNGs are isolated (Contini 1996; Coziol et al. 1996) and there is no evidence of lower abundances in the sample of luminous Arp interacting galaxies. This suggests that the low–metallicity is a characteristic of the SBNGs, which depends on their particular history of formation.

In figure 3, we show the diagram of metallicity as a function of luminosity for the galaxies of our samples. The solid line is the linear relation for the irregular and elliptical galaxies reported by ZKH. It appears that the early–type SBNGs scatter around this relation more closely than do the other galaxy types. To test this hypothesis, we calculated the differences between the abundances predicted by the linear relation and the observed abundances for each of the galaxies. The distributions of these differences are shown in figure 4. The early-type SBNGs have the same distribution as the irregulars, whereas the late–type SBNGs show the same type of deviation as the giant spirals. The hypothesis that the distributions for the early and late–type SBNGs come from the same parent population is rejected at a confidence level of 99% with a Kolmogorov–Smirnov test. The deviation of the HII galaxies from the linear relation in figure 3 and 4 is a consequence of the starbursts, because their luminosity is more affected by starbursts than that of massive galaxies, and they are therefore more lu-

minous than their metallicity suggests.

4. Discussion

Our new data on SBNGs allow us to confirm the phenomenon discovered by Coziol (1996b): the SBNGs are less chemically evolved than normal galaxies. This is inconsistent with the current hypothesis that SBNGs are evolved galaxies which were rejuvenated by interactions.

The difference between the early– and late–type SBNGs is also very meaningful, because, among the mechanisms considered by Coziol (1996b) for explaining the metal deficiency of SBNGs, only one predicts such a difference. This is the model of hierarchical formation of galaxies (Tinsley & Larson 1979), according to which ellipticals and bulges of spiral galaxies are formed by a sequence of mergers of stellar and gaseous systems. Therefore, bulge-dominated SBNGs must follow the same luminosity–metallicity relation as ellipticals. This implies that bulges of spirals are similar to elliptical galaxies, which is now supported by observations (see Jablonka et al. 1996).

If a sufficiently large fraction of gas is left from the initial merger, it will collapse to form a disk. Struck–Marcell (1981) showed that when the gas fraction of matter accreted increases, the successive generations of star have higher abundances than in the merger case. During galaxy formation, the metallicity of the gas will therefore increase faster in the disk–dominated SBNGs than in the bulge–forming SBNGs. It is very interesting to find that the disk–dominated SBNGs share the same position in the luminosity–metallicity diagram as the giant spirals. Indeed, following Kennicutt (1983), one explanation for the nearly constant star formation rates of the giant spiral galaxies over the last few Gyrs is that they have accreted extra gas in their disk.

5. Conclusion

We confirm Coziol's (1996b) claim that luminous SBNGs are less chemically evolved than normal spiral galaxies. This is a strong indication that luminous SBNGs are in fact galaxies still in the process of formation. We have also found a difference between the abundances of the early– and late–type SBNGs. This difference is consistent with the predictions of the model of hierarchical formation of galaxies. Our results suggest that galaxy formation is a continuing process and that the starburst phenomenon is a normal phase in the formation of all galaxies.

This scenario has some important implications for the observation of galaxies in formation at high redshifts. It predicts that the fraction of interacting and merging objects should be higher in the past; at high redshifts the number of early–type galaxies should be lower and the grand–design late–type spirals should appear later. These predictions may already have been verified by observations (Kauffman et al. 1996; van den Bergh et al. 1996).

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project.

Table 1

Absolute magnitudes and metallicities of the samples

sample	N	M_B	[O/H]
Giant spirals	53	−20.28 ± 1.43	0.03 ± 0.05
SBNG (early)	76	−19.68 ± 1.28	−0.25 ± 0.04
SBNG (late)	46	−19.74 ± 1.66	−0.05 ± 0.08
Irregulars	20	−15.20 ± 5.09	−1.06 ± 0.13
HII galaxies	44	−17.64 ± 2.93	−0.86 ± 0.07

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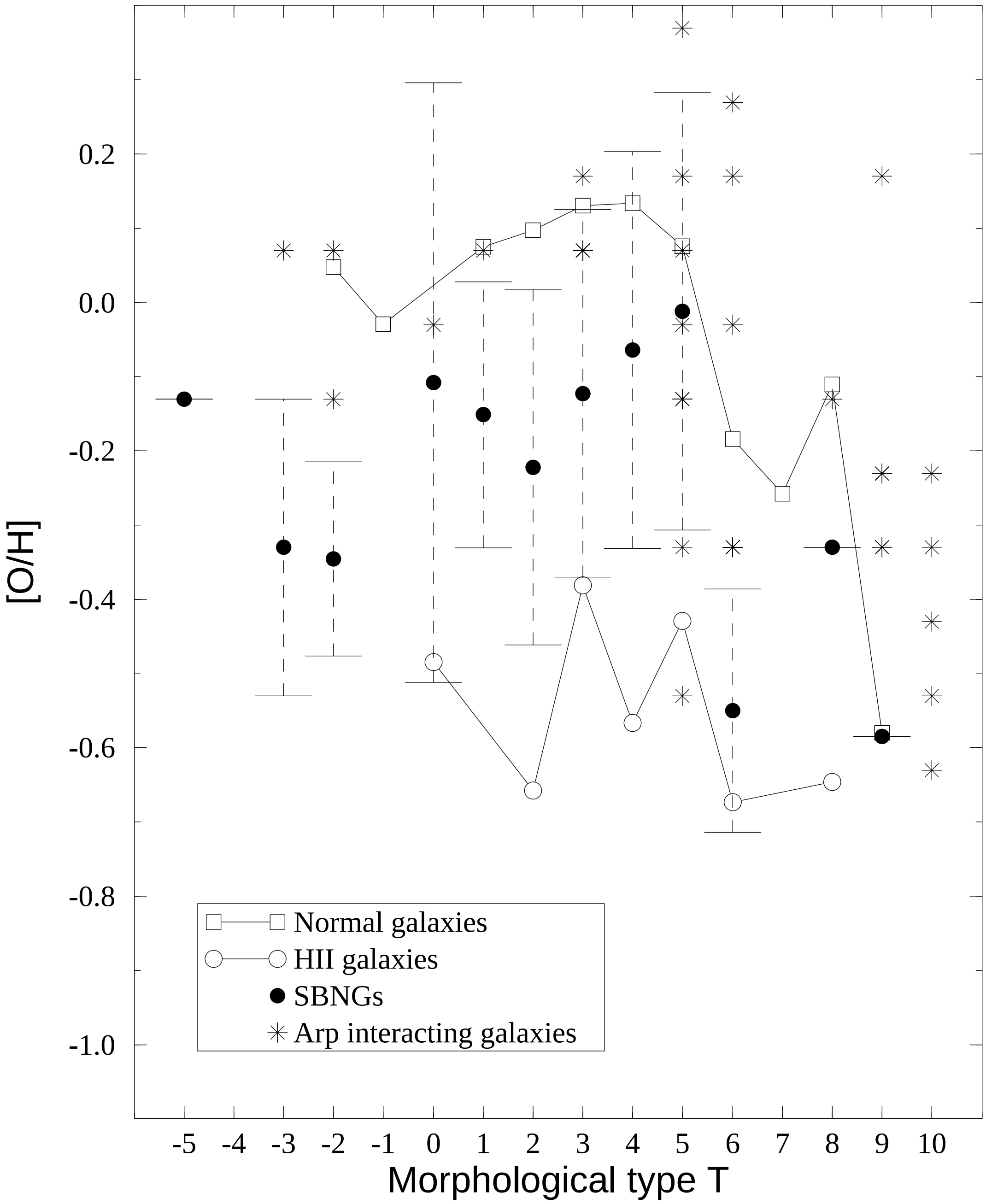
Fig. 1.— Mean metallicity as a function of morphology for SBNGs, normal galaxies and HII galaxies. The luminous SBNGs are metal deficient compared to normal galaxies, but this is not the case for the Arp interacting galaxies.

Fig. 2.— Diagram of [SII]$\lambda\lambda$6717,6731 as a function of [NII]λ6584. Dash–dotted line = lower limit for shock models; dashed line = mean of normal HII galaxies; vertical dotted line = limit for transition type galaxies. There is no indication of an additional source of ionization.

Fig. 3.— Luminosity–metallicity diagram for the different types of galaxies. Bender & Huchra's linear relation is for elliptical galaxies and is as given in ZKH (1995). It is mostly the early–type SBNGs that follow the linear relation for elliptical and irregular galaxies.

Fig. 4.— Dispersion of the deviations from the linear law ($[O/H]_{th} - [O/H]_{obs}$). The dispersion for the early–type SBNGs is the same as for the irregulars. The late–type SBNGs exceed the predicted abundances in nearly the same way as the giant spirals.


0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
[O/H]
-5
-4
-3
-2
-1
0
1
2
3
4
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6
7
8
9
10
Morphological type T
Normal galaxies
HII galaxies
SBNGs
Arp interacting galaxies

Fig. 1

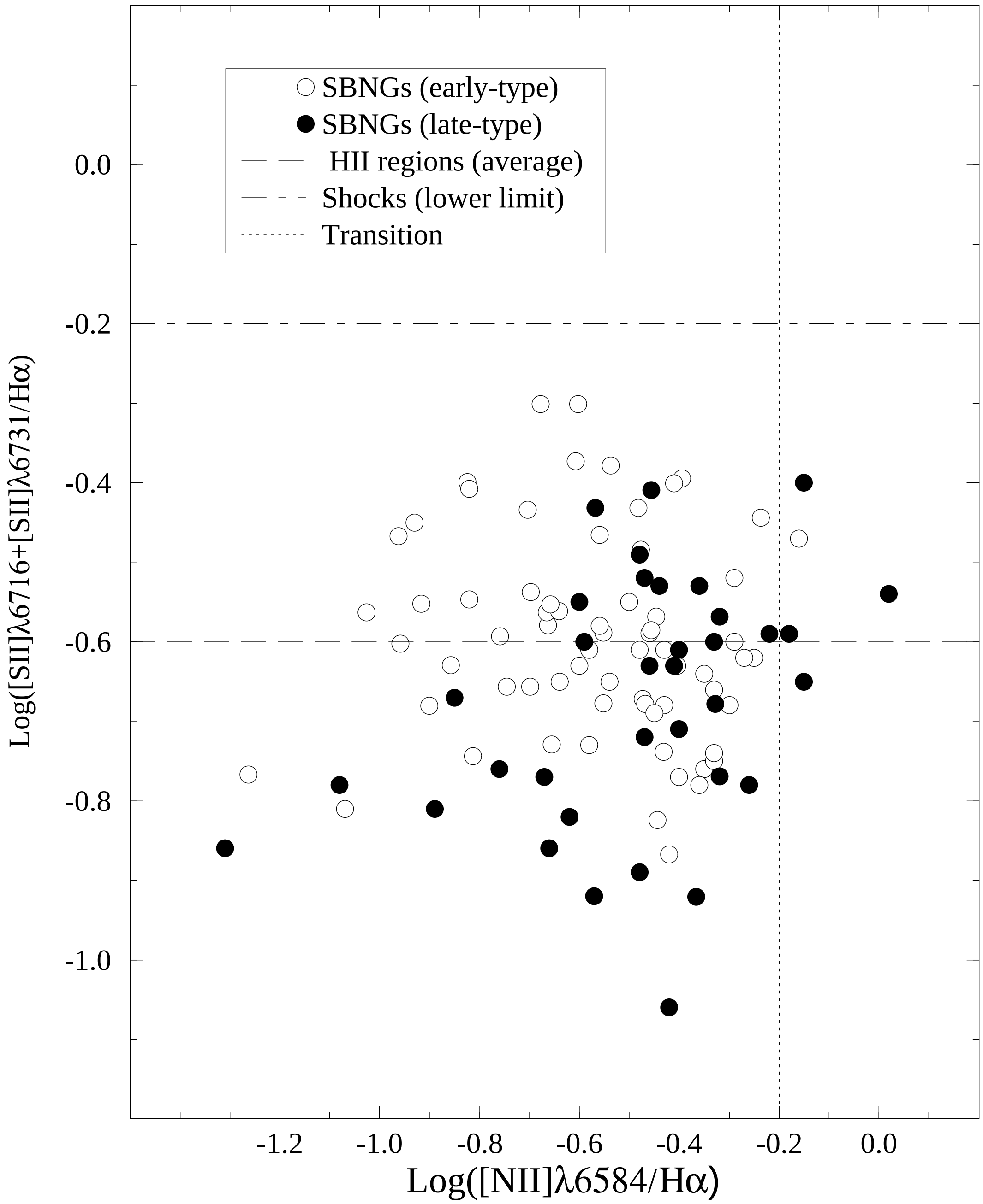
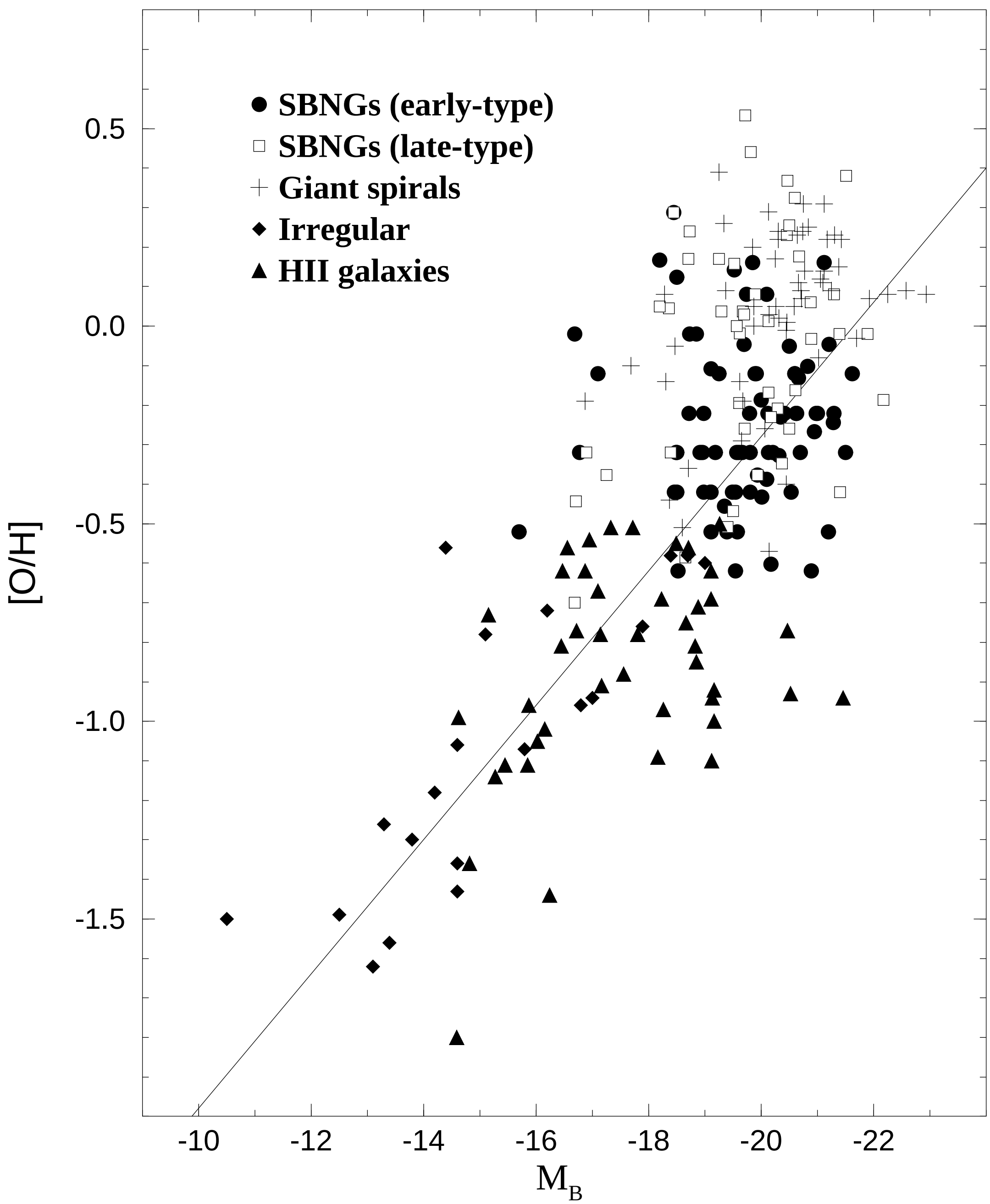

SBNGs (early-type)
SBNGs (late-type)
HII regions (average)
Shocks (lower limit)
Transition
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Log([SII]λ6716+[SII]λ6731/Hα)
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
Log([NII]λ6584/Hα)

Fig. 2



SBNGs (early-type)
SBNGs (late-type)
Giant spirals
Irregular
HII galaxies
0.5
0.0
-0.5
-1.0
-1.5
[O/H]
-10
-12
-14
-16
-18
-20
-22
M_B

Fig. 3

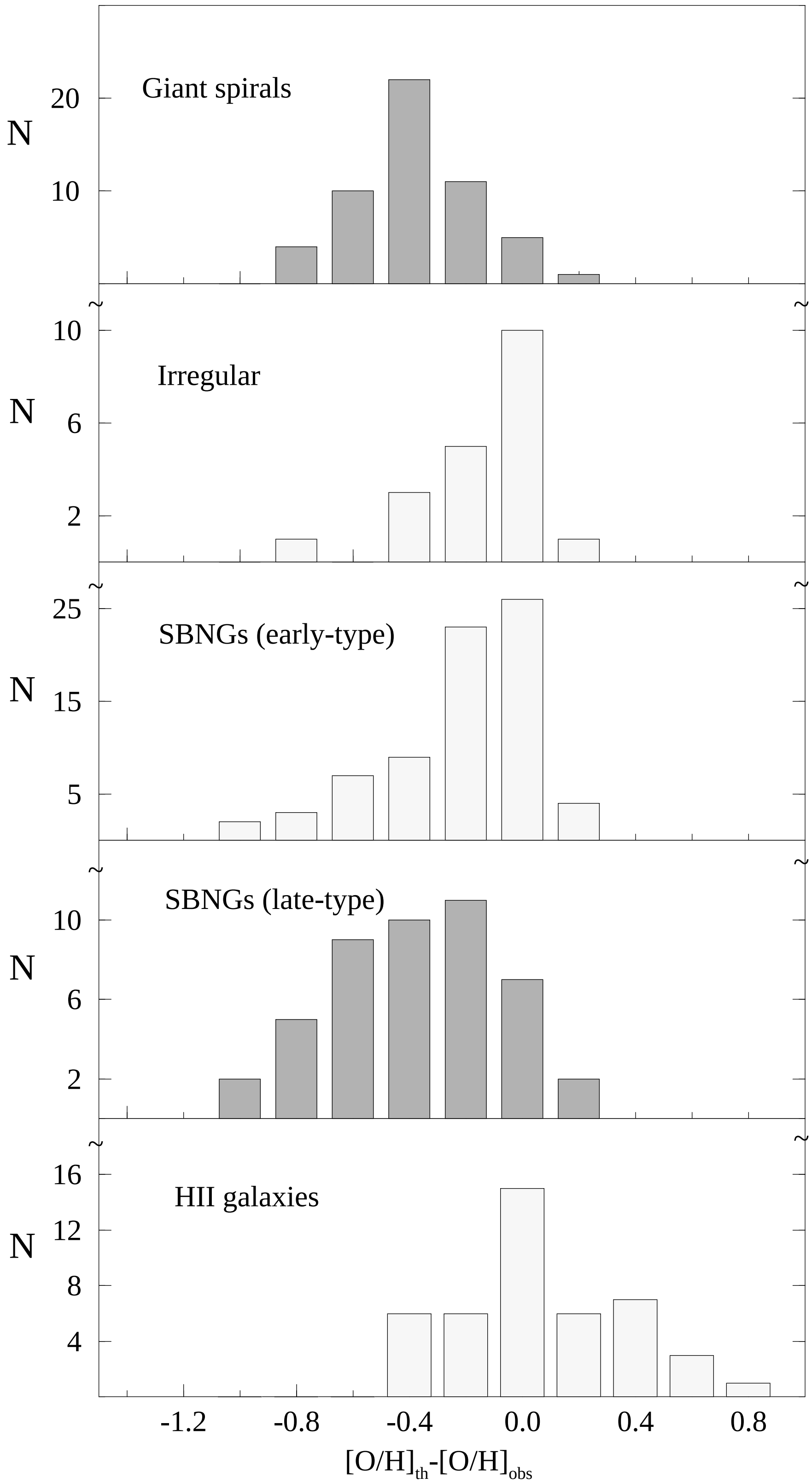

Giant spirals
Irregular
SBNGs (early-type)
SBNGs (late-type)
HII galaxies
N
20
10
6
2
25
15
5
16
12
8
4
-1.2
-0.8
-0.4
0.0
0.4
0.8
[O/H]th-[O/H]obs

Fig. 4